Development of supply chain risk mitigation framework in the digital era

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Abstract. In the context of digital transformation, supply chains contend with various challenges, and reconfiguration of supply chain design has obtained significant consideration in today's digital era. This paper aims to reveal the adaptability of Industry 4.0 technologies to risk mitigation in supply chain design and develop a conceptual Framework. Analytic Hierarchy Process (AHP) method was used to create a conceptual risk mitigation framework and validated it through a comprehensive questionnaire collected by industrial and academic experts and academics and carried out the pairwise comparison between the main criteria and sub-criteria The contribution of this study lies in the taxonomy study, and findings revealed that digitalisation of supply chain design for risk mitigation shed light on future research. Additionally, it focuses on the potential to enhance supply networks' efficiency and responsiveness.

1 Introduction

Supply chain management (SCM) has become a critical factor in gaining a competitive edge. With the evolution of digital technologies, Industry 4.0 initiates opportunities for supply chain design and reconfiguration.[1] described that the supply chain involves managing, planning, and controlling the products and services by interconnecting between supplier and customer. Digital transformation provides opportunities to evolve into collaborative value networks [2].

Effective SCM relies on robust risk mitigation practices, mainly in the face of uncertainty. Over the past two decades, researchers have increasingly explored dynamic supply chain design to enhance by mitigating the risk. Risk management plays a key role in operating SC effectively in a variety of uncertain circumstances. Over the past years, researchers have contributed to concentrating on and mitigating risks [3]. Giannakis & Papadopoulos [4] stated that supply chain nodes need to be assessed to identify the various risks and the risk levels.

This interest has been improved by the impact of digital technologies on SCM processes. Digital technologies such as big data analytics (BDA), advanced manufacturing technologies with sensors, advanced robotics, and tracking and tracing technologies facilitate the

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development of digital supply chains and smart operations [5]. Bressanelli *et al*. [6] observed that SC reconfiguration involves various challenges and supply chain designers carefully analyse each aspect and conduct a viability assessment before implementing any redesign structures with the firm. This paper assists in identifying the main factors that impact the dynamic reconfiguration of supply chain design by creating a questionnaire to validate and relate the impact of Industry 4.0 and digital technologies to mitigating the supply chain risk level.

2 Research Methodology

The analytic Hierarchy Process (AHP) is a multi-criteria decision-making technique used to analyse Multiple Attribute Decision-Making (MADM) problems. Thomas L. Saaty initially formed it in 1980 and has been studied and improved since then [7]. Jaberidoost *et al.*[8] described that pairwise comparisons in AHP are utilised to verify preferences among criteria or alternatives. AHP modifies the comparison into numeric numbers, which are then further processed and contrasted. Each factor's weight permitted the evaluation of the criteria inside the hierarchy [9].

To validate the proposed framework, a questionnaire was developed to collect the data from 100 industrial and academic experts. The questionnaire was designed to make pairwise comparisons between the two criteria at each level at a time to determine which criterion is the most important and to identify the degree of importance on a scale between one (equal importance) and nine (more important) of the most important criteria [10]. All the respondents agreed about the proposed framework and demonstrated positive responses and it can be considered as a validation of the framework.

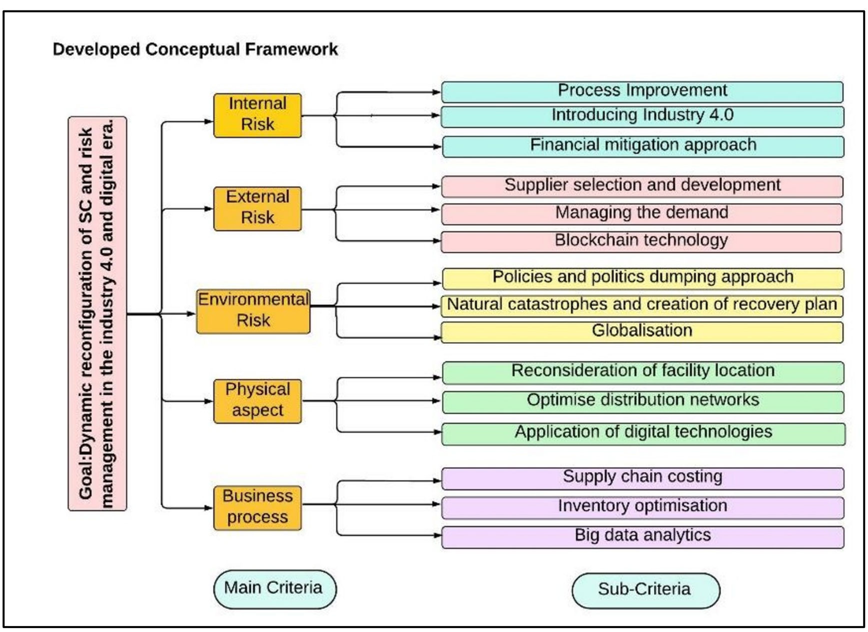

Fig. 1. The developed conceptual framework for supply network risk mitigation- I4.0 approach.

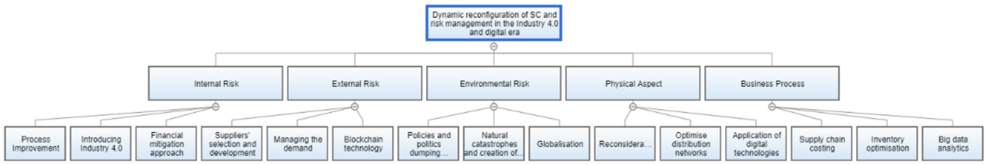

Fig. 2. The developed conceptual framework implementation within the AHP software.

3 Results and Discussion

To validate the proposed framework, a questionnaire was designed to collect data from 100 industrial and academic experts. The questionnaire was developed based on the main criteria, sub-criteria, and alternatives (Fig.1).

Based on the results of the relative importance of the criteria and sub-criteria presented in Fig. 3, it is evident that the three main criteria located in the highest indicated that the physical aspect was the most important holds a relative importance of 28.01%, and internal risk holds a relative importance of 26.16%, and the business process was the least ranking with relative importance of 24.46% compared to other criteria in the proposed framework. Additionally, the sub-criterion with the highest significance is the application of digital technologies, accounting for 9.16%.

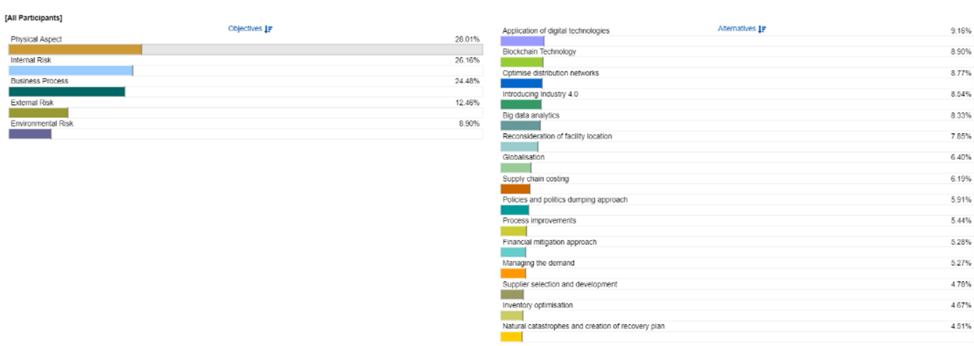

Fig. 3. The relative importance of the criteria and sub-criteria of the proposed framework.

3.1 Sensitivity Analysis

Sensitivity analysis in AHP examines how changes in input values or weights impact the final priority rankings, assessing decision-making stability and robustness. By varying inputs within a specified range, it reveals the sensitivity of rankings to these changes. According to [11], not many relative weight changes could make a major difference in the final ranking. It can be used for method validation and helps to steady the rank order. The sensitivity analysis tool is beneficial for understanding how decisions are effortlessly affected by other factors within the framework.

This analysis enables informed decision-making based on factors' varying degrees of influence. Identifying critical criteria or alternatives affecting outcomes and understanding associated uncertainties and risks are benefits of sensitivity analysis in AHP [12].

In this study, sensitivity analysis incorporated into the AHP was utilised to dynamically amend the priorities of the sub-criteria. Therefore, the impact of changing the priority of the five main criteria “Internal Risk, External Risk, Environmental Risk, Physical Aspect and Business Process” on overall results has been investigated [13]. Fig. 3 represents the priorities of the main criteria and the correlated ranking for sub-criteria, this indicates the main scenario.

The following figure represents the sensitivity performance of the first three main criteria based on the sensitivity of their benchmarks. In the first scenario shown in Fig. 4, the priority of "Physical Aspect" was raised to the highest priority (from 28.01% to 37.61%). The highest and lowest priority of the final ranking of sub-criteria were sustained, while the “supply chain costing” received the seventh priority with 6.35% instead of “globalisation”.

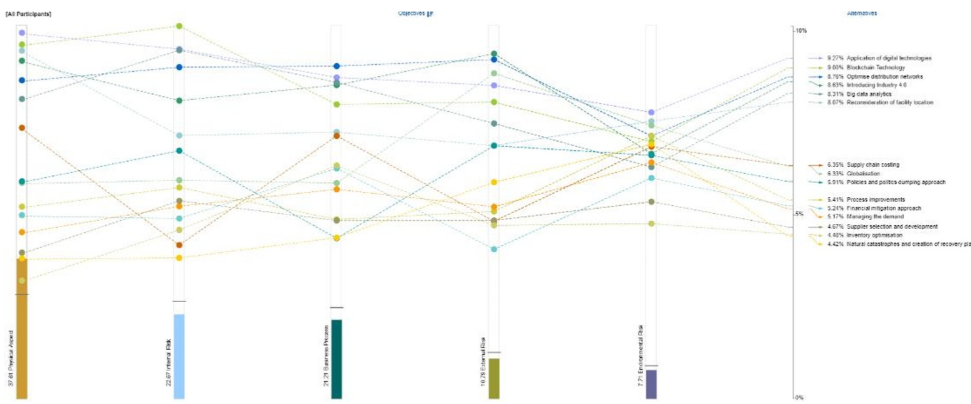

Fig. 4. First scenario of Sensitivity analysis.

In the second scenario shown in Fig. 5, the priority of "Internal Risk" was raised to the highest priority (from 26.16% to 36.02%). The highest and lowest priority of the final ranking of sub-criteria were preserved whilst “supply chain costing” received the eighth priority with 6.35% instead of “globalisation” and “Managing the demand” received the eleventh priority with 5.26% instead of “Financial mitigation approach”.

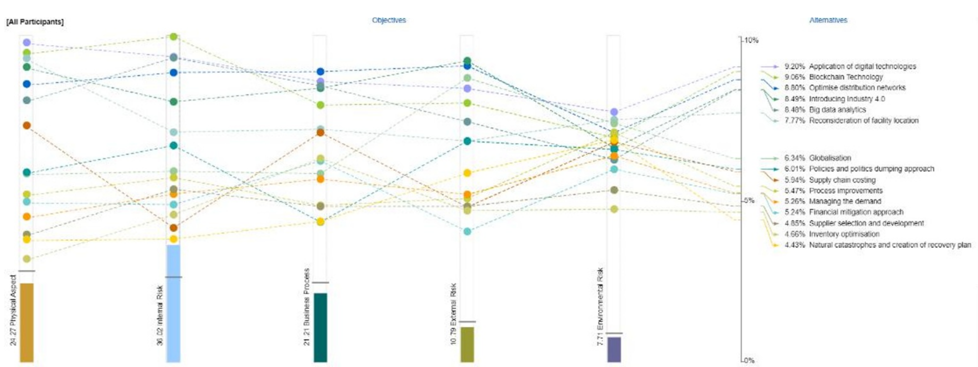

Fig. 5. Second scenario of Sensitivity analysis.

Fig. 6 shows the third scenario when the priority of “Business Process” was raised to the highest priority (from 24.48% to 32.13%). The highest and lowest priority of the final ranking of sub-criteria were sustained, while the “Financial mitigation approach” received the tenth priority with 5.39% instead of "Process improvement" and "Inventory optimisation" received the thirteenth priority with 4.85% instead of "Supplier selection and development".

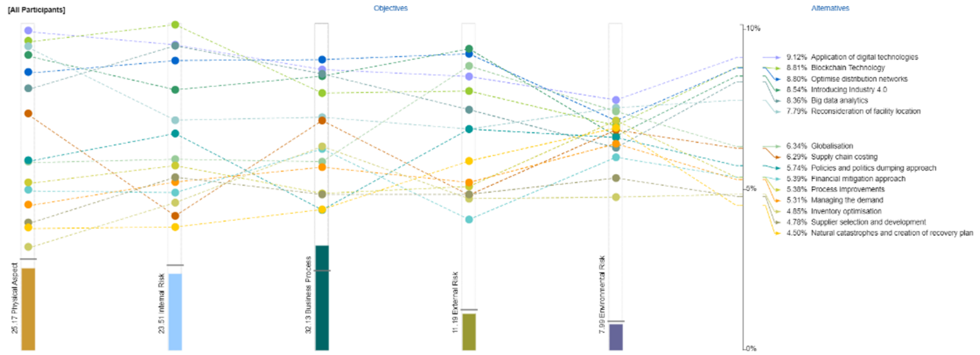

Fig. 6. Third scenario of Sensitivity analysis.

Sensitivity analysis has been applied in this study to understand how the changes in the priority of one criterion affect another. This indicates that the model demonstrates consistency, with all the sub-criteria remaining with minor changes in their priorities and percentage of sub-criteria. This allows for the prioritisation of objectives over sub-criteria to evaluate the sensitivity of objectives in relation to alternatives.

4 Conclusion

In this study, the Analytical Hierarchy Process (AHP) methodology was adapted and utilised to examine the relative importance of the factors in reducing the risk level of supply chain design when reconfiguring the supply chain. The benchmark for supply chain design reconfiguration was the development of the framework for risk mitigation, which was proposed and validated based on data collected from 100 industrial and academic experts considering the weight of each criterion and Industry 4.0 technologies. The application of this framework has effectively supported the company in evaluating its current situation when reconfiguring the supply chain, identifying the Industry 4.0 and digital technology requirements, and determining what technologies need to be implemented to mitigate the risk level. The main criteria for reconfiguring supply chain design for risk mitigation were carefully chosen based on the literature review and the field's developing trends.

This study shows that the application of digital technologies such as blockchain technology, big data analytics, and cloud computing is the most required for risk mitigation, and the optimal distribution network and reconsidering the facility location were most significant in the physical aspect. Overall, this study provides the road map for future research work by identifying the main criteria and sub-criteria for reconfiguring the supply chain for risk mitigation and the potential of digital technologies for risk management by developing the conceptual framework. With these advancements, organisations can enhance their supply chains by restructuring operations to mitigate the risk level by ensuring seamless processes and satisfying customer experiences.

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